



ST. ANDREW'S JUNIOR COLLEGE
JC2 PRELIMINARY EXAMINATIONS
HIGHER 2

CANDIDATE
NAME

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CLASS

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CHEMISTRY

9729/02

Paper 2 Structured Questions

2 September 2025

Candidates answer on the Question Paper.

2 hours

Additional Materials: Data Booklet

READ THESE INSTRUCTIONS FIRST

Write your name and class on all the work that you hand in.

Write in dark blue or black pen.

You may use a HB pencil for any diagrams or graphs.

Do not use staples, paper clips, glue or correction fluid.

Answer **all** questions in the **spaces provided** on the Question Paper.

The use of an approved scientific calculator is expected, where appropriate.

A Data Booklet is provided.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [] at the end of each question or part question.

For Examiner's Use		
Q1		21
Q2		7
Q3		16
Q4		12
Q5		19
Total		75

- 1 (a) Titanium dioxide, TiO_2 , is a white solid, which is an amphoteric oxide. In the structure of titanium dioxide, the titanium ion is bonded to six oxide anions.

- (i) Complete the electronic configuration of a titanium atom.

$1s^2$ [1]

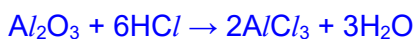
$1s^2 2s^2 2p^6 3s^2 3p^6 3d^2 4s^2$

- (ii) Suggest the shape around the titanium ion in titanium dioxide. [1]

Octahedral

- (b) (i) Aluminium oxide is another example of an amphoteric oxide.

Write two equations to illustrate the reaction of Al_2O_3 with an acid and a base of your choice respectively. [2]



- (ii) The ionic radius of Al^{3+} is 0.050 nm and Ti^{2+} is 0.086 nm.

Explain the difference in ionic radii between Al^{3+} and Ti^{2+} . [2]

Ti^{2+} has a higher nuclear charge than Al^{3+} . Ti^{2+} also has more filled inner shells / electron shells / (principal) quantum shells and the valence electrons are further away from the nucleus and shielding effect increases. The valence electrons are less strongly attracted to the nucleus. Ti^{2+} has a larger ionic size than Al^{3+} .

- (c) Titanium(II) chloride is prepared by the thermal decomposition of TiCl_3 at 500°C . The reaction is driven by the loss of volatile TiCl_4 .



- (i) State and explain the sign for ΔS^\ominus . [1]

ΔS^\ominus is positive or >0 as there is an increase in disorderliness / decrease in orderliness / more ways of arranging when gaseous TiCl_4 / more gaseous molecule is formed.

- (ii) Deduce the sign of the enthalpy change, ΔH , of the thermal decomposition of TiCl_3 , given that the decomposition is spontaneous only at high temperature. Explain your answer. [1]

$$\Delta G = \Delta H - T\Delta S$$

The reaction is spontaneous only at high temperature, hence ΔG is negative at high temperature. Since ΔS is positive, ΔH must be positive.

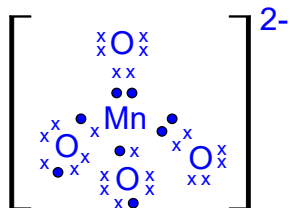
- (iii) Explain why TiCl_3 forms a violet solution, but TiCl_4 forms a colourless solution. [2]

TiCl_4 does not have any 3d electrons, hence no d-d transition can occur.

However, TiCl_3 has partially filled 3d subshells / orbitals which split into 2 energy levels in the presence of ligands. When an electron from the lower energy d orbital is promoted to a higher energy d orbital, visible light is absorbed. The complementary colour observed is reflected / colour observed is the complementary of light absorbed.

- (d) Another transition element that is bonded to oxygen atoms is manganese. Two examples are manganate(VI) ion, MnO_4^{2-} , and manganate(VII) ion, MnO_4^- .

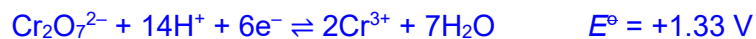
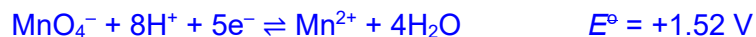
- (i) Given that the structure of MnO_4^{2-} is similar to that of SO_4^{2-} , draw the 'dot-and-cross' diagram of MnO_4^{2-} and state its bond angle. [2]



109.5°

- (ii) Acidified potassium manganate(VII), KMnO_4 , and acidified potassium dichromate, $\text{K}_2\text{Cr}_2\text{O}_7$, can be used as oxidising agents in organic reactions. [2]

With reference to relevant E° values, suggest why KMnO_4 is a stronger oxidising agent than $\text{K}_2\text{Cr}_2\text{O}_7$.



$E^\circ(\text{MnO}_4^-/\text{Mn}^{2+})$ is more positive as compared to $E^\circ(\text{Cr}_2\text{O}_7^{2-}/\text{Cr}^{3+})$. Hence MnO_4^- is easier to be reduced and is a stronger oxidising agent.

- (e) **A**, **B** and **C** are isomers with the molecular formula, $\text{C}_5\text{H}_{10}\text{O}$, that contains one or two of the following functional groups.

- Alkene
- Alcohol
- Carbonyl

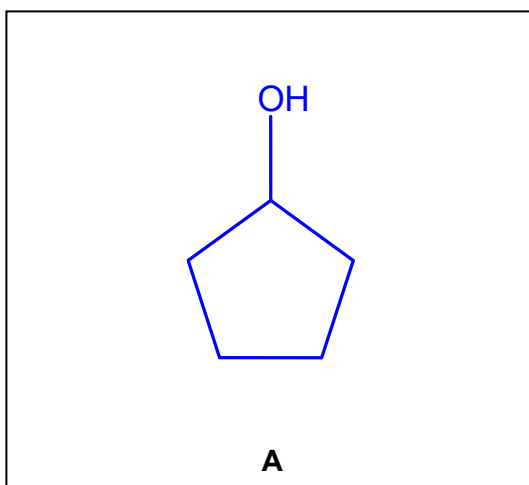
Reactions are carried out on **A**, **B** and **C** and the observations are shown in Table 1.1.

Table 1.1

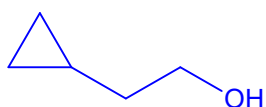
	with acidified $\text{K}_2\text{Cr}_2\text{O}_7$ (aq)	with acidified KMnO_4 (aq)	with 2,4-DNPH	with Br_2 (aq)
A	orange to green	purple to colourless	no reaction	no reaction
B	no reaction	no reaction	orange precipitate	no reaction
C	no reaction	purple to colourless	no reaction	orange to colourless

- (i) **A** is a cyclic compound and does not rotate plane of polarised light. Draw the structure of **A**.

[1]

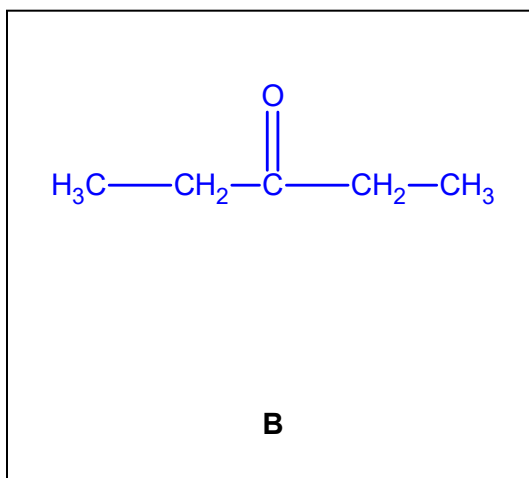


Or



- (ii) **B** is a symmetrical molecule. Draw the structure of **B**.

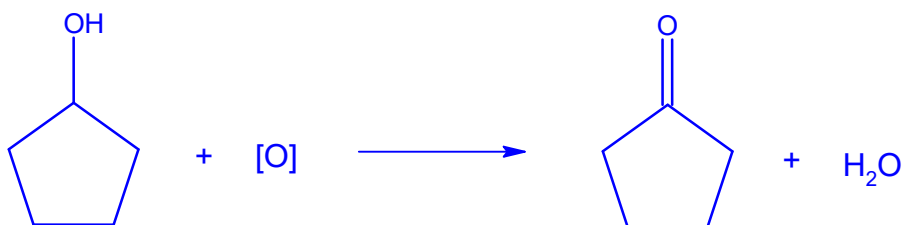
[1]



- (iii) Write the equation for the reaction which occurs when **A** reacts completely with an excess of acidified potassium dichromate(VI). Use [O] to represent the oxidising agent in the reaction.

[1]

[TURN OVER]



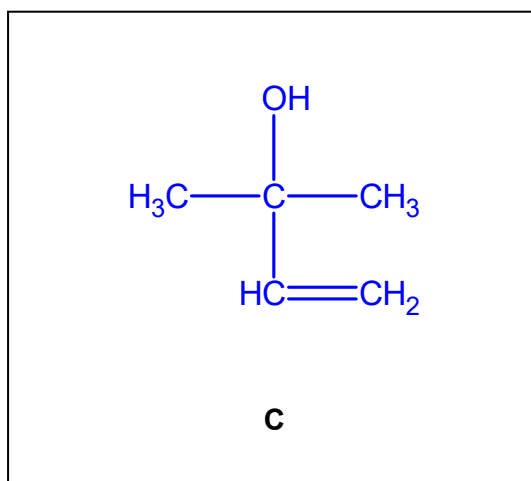
Examiner's Comment:

- Common mistakes include:
 - Writing the molecular formula instead of giving the structural formula of A and the product.
 - Not balancing the equation with H₂O or [O]

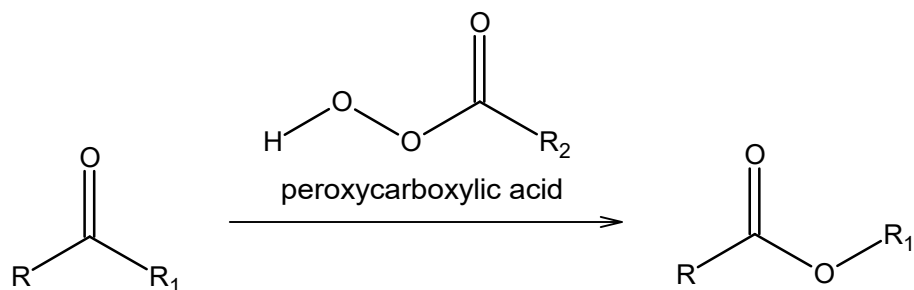
(iv) State all possible functional groups in **C**. [1]

Alkene and tertiary alcohol

(v) **C** is unable to exhibit stereoisomerism. Draw the structure of **C**. [1]

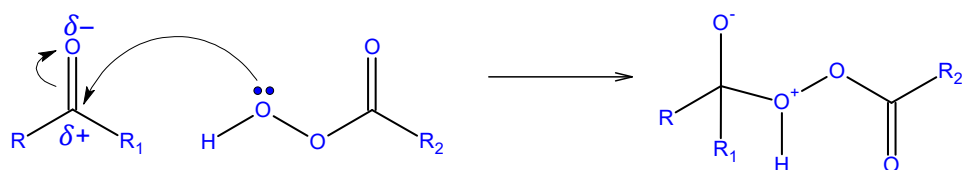


(f) Ketones can undergo oxidation forming esters through the Baeyer–Villiger oxidation reaction by using peroxycarboxylic acids as shown in the equation below. [2]



The first step of the mechanism of the Baeyer–Villiger oxidation reaction involves the nucleophilic attack of the lone pair of electrons on the oxygen atom bonded to the hydrogen atom in the peroxycarboxylic acid to the carbonyl carbon in the ketone.

Draw the first step of the mechanism of the Baeyer–Villiger oxidation reaction. Show all relevant dipoles, curly arrows and the structure of the intermediate.



[Total: 21]

- 2 Ozone, O_3 , plays a crucial role in the Earth's atmosphere by absorbing harmful ultraviolet radiation. It is also widely used for its oxidising and disinfecting properties. For example, ozone can be dissolved in ground water or drinking water for disinfection and water quality enhancement.

Fig. 2.1 shows one possible structure of O_3 (g).

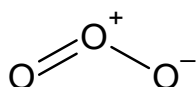
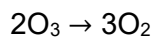


Fig. 2.1

- (a) The overall reaction for the decomposition of ozone can be represented as follows.



[TURN OVER]

The rate of decomposition of ozone in ground water, at pH 8, was investigated and the following results were obtained. The reaction is first order with respect to ozone.

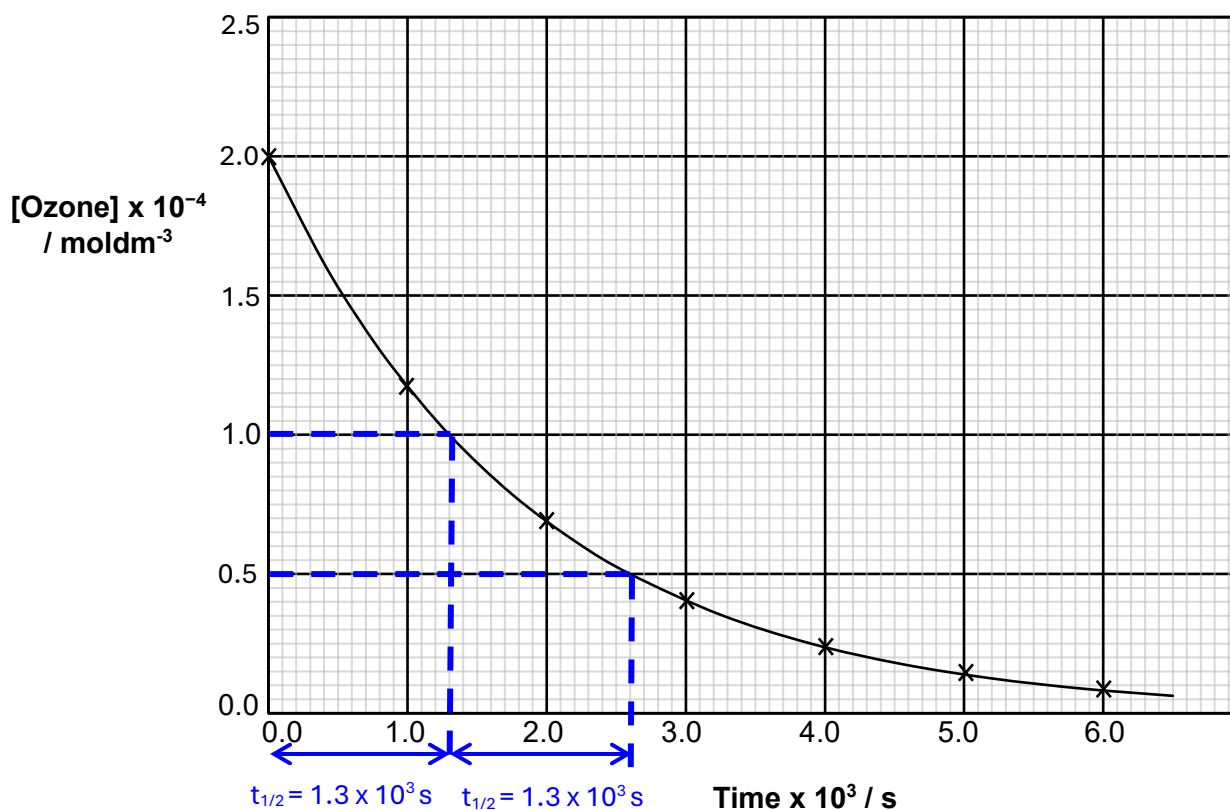


Fig. 2.2

- (i) Define the term *order of reaction*. [1]

It is the power to which the concentration of the reactant is raised in the experimentally determined rate equation.

- (ii) Use the graph in Fig. 2.2 to show that the overall order of reaction is first order. [1]

Since the half-life of the reaction for decomposition of ozone is constant at $1.3 \times 10^3 \text{ s}$, the order of the reaction is first order with respect to [ozone].

for correct half-life with working on the graph that shows 2 half-lives

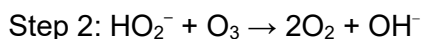
[TURN OVER

- (iii) Hence, calculate the value of the rate constant, k . Include its units. [1]

$$t_{1/2} = \frac{\ln 2}{k}$$

$$\text{Using } t_{1/2} = 1.3 \times 10^3 \text{ s, } k = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{1.3 \times 10^3} = 5.33 \times 10^{-4} \text{ s}^{-1} \text{ [with units]}$$

- (iv) The presence of OH^- was found to initiate the decomposition of ozone and the following reaction mechanism was suggested.



State the role of OH^- in this mechanism and explain how the presence of OH^- would affect the rate of the reaction.

[1]

OH^- is acting as a catalyst as it provides an alternative pathway to lower the activation energy and increases the rate of reaction.

- (b) Ozone is a strong oxidising agent, useful for oxidative cleavage of alkenes to form carbonyl compounds.

The reaction of ozone with alkenes can be shown in Fig. 2.3.

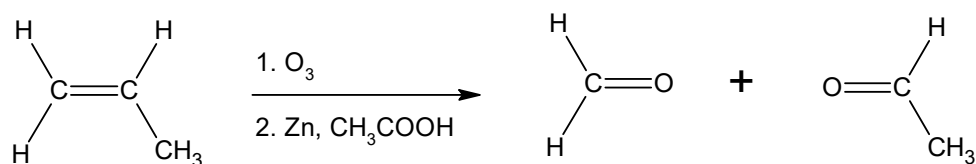


Fig. 2.3

The first step in the mechanism is the initial electrophilic attack by ozone to the carbon-carbon double bond, which then forms the molozonide intermediate. In the second step, the unstable molozonide intermediate undergoes further reaction and breaks apart to form a carbonyl oxide and a carbonyl compound.

[TURN OVER

The first and second step of the mechanism is shown in Fig. 2.4.

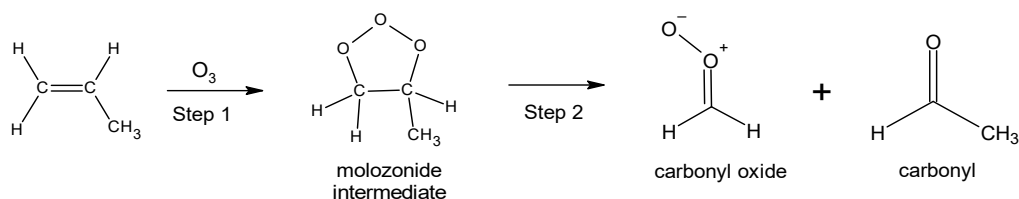


Fig. 2.4

The carbonyl oxide and carbonyl then further react to form the respective carbonyl compounds.

- (i) 2-methylbut-2-ene reacts with ozone in a similar reaction to that in Fig. 2.3.

On Fig. 2.5, draw the structure of the molozonide intermediate and suggest the mechanism for the reaction of 2-methylbut-2-ene with ozone in step 1 to form the molozonide intermediate. Include all relevant lone pairs and three curly arrows.

[2]

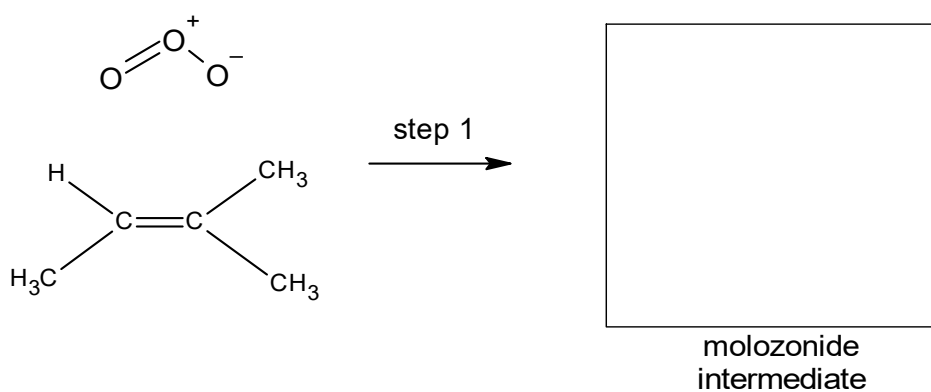
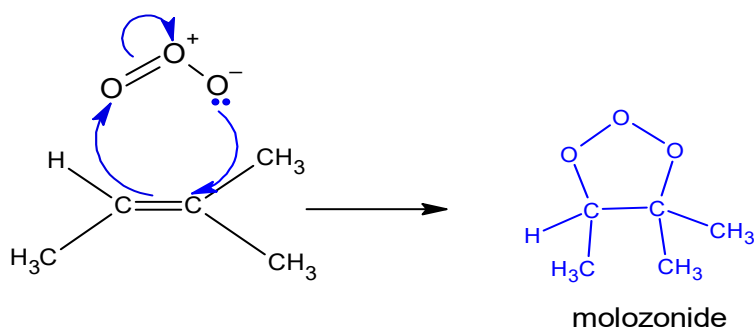
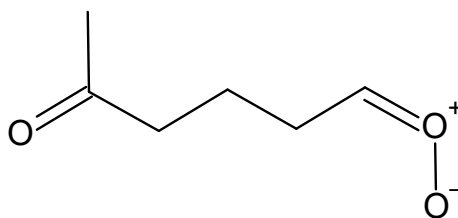


Fig. 2.5

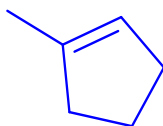


[TURN OVER]

- (ii) Compound **F** was formed in step 2 of the mechanism in Fig 2.4 when ozone reacts with another alkene, **G**. Suggest the identity of **G**.

Compound **F**

[1]



[Total: 7]

- 3 Heavy metal contamination in water poses significant risks to environmental and human well-being. Common heavy metals found in water include cadmium (Cd), lead (Pb) and mercury (Hg).

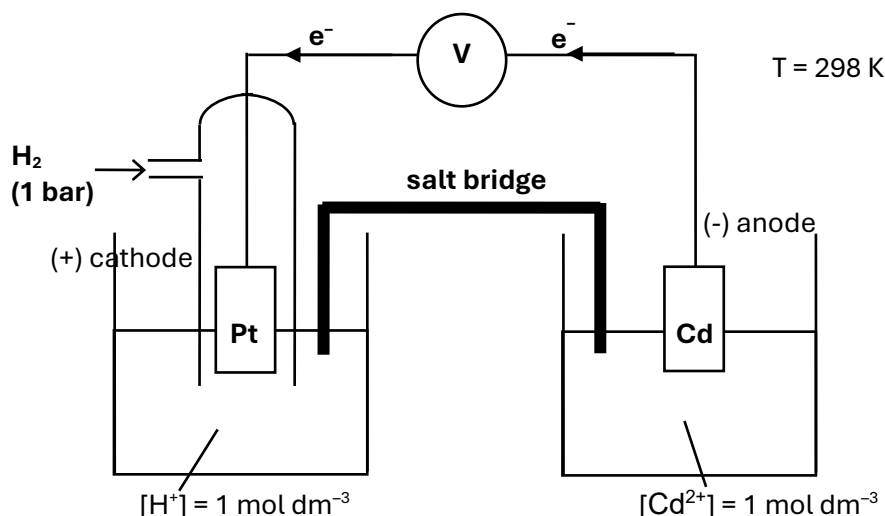
(a) The standard electrode potential of the $\text{Cd}^{2+}(\text{aq})/\text{Cd}(\text{s})$ electrode is -0.403V .

- (i) Define the term *standard electrode potential*, E° . [1]

The standard electrode potential is the potential difference between standard hydrogen electrode and a half-cell / half-cells of a cell, measured at 298 K, in which the concentration of any reacting species is 1 mol dm⁻³ and any gaseous species is at 1 bar.

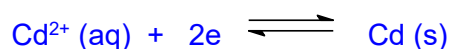
- (ii) Draw a fully labelled diagram of the experimental set-up used to measure the standard electrode potential, E° , of the $\text{Cd}^{2+}(\text{aq})/\text{Cd}(\text{s})$ half-cell. [2]

[TURN OVER]



- (iii) Predict how the electrode potential, E^\ominus , of $\text{Cd}^{2+}(\text{aq})/\text{Cd}(\text{s})$ will be affected when aqueous sodium hydroxide is added to the $\text{Cd}^{2+}(\text{aq})/\text{Cd}(\text{s})$ half-cell. Explain your answer. [2]

When $\text{OH}^- (\text{aq})$ ions were added to the half cell, $\text{Cd}(\text{OH})_2$ will be formed and concentration of Cd^{2+} will decrease.



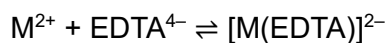
The equilibrium position shifts left to increase $[\text{Cd}^{2+}]$. Hence, E_{anode} becomes more negative.

- (b) A water source was found to be contaminated by heavy metal contaminant, Pb^{2+} .

To determine whether the water is safe to drink, complexometric back titration was employed to determine the concentration of Pb^{2+} in a water sample.

The water sample containing Pb^{2+} will be reacted with an excess amount of EDTA^{4-} , where a lead-EDTA complex will be formed in the process.

The general reaction of metal ion, M^{2+} and EDTA^{4-} is as shown:



[TURN OVER

The remaining amount of EDTA^{4-} is then determined by titrating with zinc sulfate, with Eriochrome Black T as an indicator.

- (i) 10.0 cm^3 of $5.0 \times 10^{-7} \text{ mol dm}^{-3}$ of EDTA^{4-} was added to 10.0 cm^3 of water sample containing Pb^{2+} . The resulting solution was found to require 10.0 cm^3 of $2.0 \times 10^{-7} \text{ mol dm}^{-3}$ of zinc sulfate solution for complete reaction.

Calculate the amount, in moles, of Pb^{2+} present in 10.0 cm^3 of the water sample. [1]

$$\text{No of moles of } \text{Zn}^{2+} = \text{No. of remaining } \text{EDTA}^{4-} = 2.00 \times 10^{-9} \text{ mol}$$

No of moles of Pb^{2+} reacted

$$= \text{Initial amount of } \text{EDTA}^{4-} - \text{amount of remaining } \text{EDTA}^{4-}$$

$$= 5.00 \times 10^{-9} - 2.00 \times 10^{-9} = 3.00 \times 10^{-9} \text{ mol}$$

- (ii) Calculate the mass of Pb^{2+} , in mg, present in 1 dm^3 of water sample.

Given that the safe limit of maximum mass of Pb^{2+} is $0.0100 \text{ mg dm}^{-3}$, comment on whether the water is safe to drink. [2]

Mass of Pb^{2+} in 10.0 cm^3 of water sample

$$= 3.00 \times 10^{-9} \times 207.2 = 6.216 \times 10^{-7} \text{ g}$$

Mass of Pb^{2+} in 1 dm^3 of water sample

$$= 6.216 \times 10^{-7} \times \frac{1000}{10} = 6.216 \times 10^{-5} \text{ g} = 0.0622 \text{ mg}$$

The concentration of Pb^{2+} has exceeded the safe limits, the water is not safe for drinking.

- (iii) Hydrogen sulfide, H_2S , is added to another 1 dm^3 of water sample containing $1.0 \times 10^{-9} \text{ mol dm}^{-3}$ of Hg^{2+} and Pb^{2+} each.

Table 3.1 shows the K_{sp} values for the corresponding metal sulfides.

Table 3.1

Metal Sulfide	$K_{\text{sp}} / \text{mol}^2\text{dm}^{-6}$
PbS	9×10^{-29}
HgS	2×10^{-53}

Calculate the minimum concentration of hydrogen sulfide added to remove the maximum concentration of Hg^{2+} without precipitating Pb^{2+} .

Hence, determine the maximum mass of HgS precipitated in 1 dm^3 .

[2]

Ionic Product = K_{sp} of PbS

$$(1 \times 10^{-9})[\text{S}^{2-}(\text{aq})] = 9 \times 10^{-29}$$

$$[\text{S}^{2-}(\text{aq})] = (9 \times 10^{-29}) / (1 \times 10^{-9}) = 9.0 \times 10^{-20} \text{ mol dm}^{-3}$$

Ionic Product = K_{sp} of HgS

$$[\text{Hg}^{2+}(\text{aq})](9.0 \times 10^{-20}) = 2 \times 10^{-53}$$

$$[\text{Hg}^{2+}(\text{aq})] = 2.22 \times 10^{-34} \text{ mol dm}^{-3}$$

$[\text{Hg}^{2+}]$ is almost precipitated since $[\text{Hg}^{2+}]$ in solution \ll initial $[\text{Hg}^{2+}]$

Mass of HgS

$$= 1 \times 10^{-9} \times (200.6 + 32.1) = 2.33 \times 10^{-7} \text{ g}$$

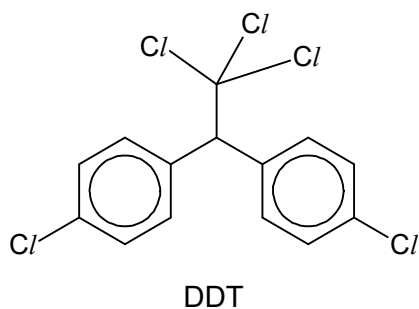
OR

Mass of HgS

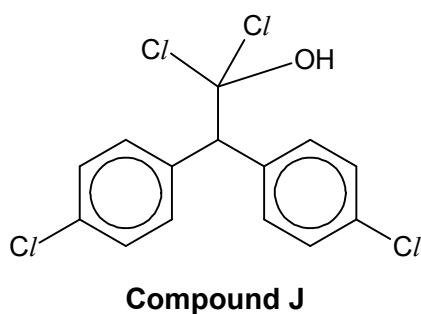
$$= (1 \times 10^{-9} - 2.22 \times 10^{-34}) \times (200.6 + 32.1) = 2.33 \times 10^{-7} \text{ g}$$

- (c) DDT is a common ingredient in insecticides and it can enter groundwater as an organic pollutant through processes like runoff and leaching.

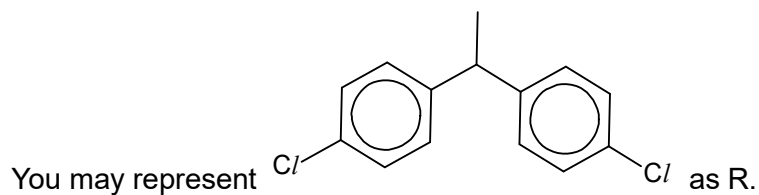
[TURN OVER]



- (i) A student proposed that compound **J** will be formed when DDT is reacted with hot aqueous sodium hydroxide, assuming that the rate of reaction is independent of the concentration of NaOH.

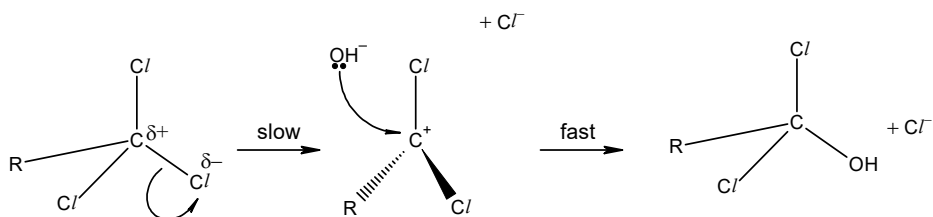


Name and describe the mechanism for the reaction between DDT and hot aqueous sodium hydroxide to form compound **J**. Include all relevant lone pairs, dipoles, curly arrows and charges. Include the structure of the organic intermediate.



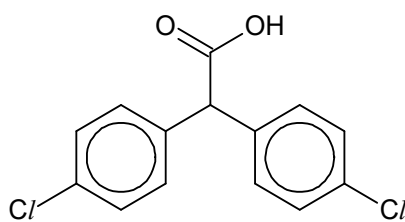
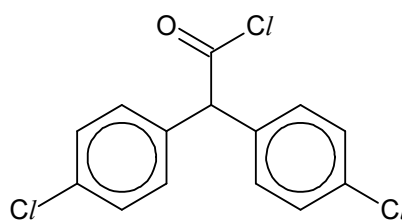
[2]

Nucleophilic Substitution, S_N1



[TURN OVER]

- (ii) It was found that compound **K** is formed when DDT reacts with hot aqueous sodium hydroxide. **K** then reacts with phosphorus pentachloride to form compound **L**.

compound **K**compound **L**

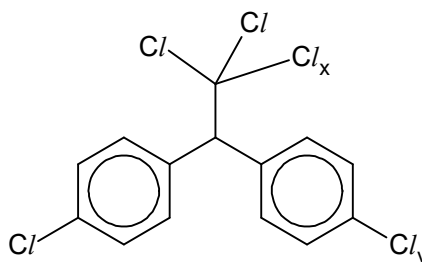
When the same amount of compounds **K** and **L** (not necessarily in that order) are added to separate and equal volumes of water, solutions are formed with pH values of 0.5 and 3.0.

Suggest which pH value is associated with compounds **K** and **L**. Explain your answer.

[2]

pH 0.5 - Compound **L** pH 3.0 - Compound **K**
L is hydrolysed by water to form carboxylic acid and HCl . The strong acid HCl , or fully dissociates, accounts for the low pH.

- (iii) Explain the difference in reactivity of the two chlorine atoms labelled Cl_x and Cl_y in DDT towards hot aqueous sodium hydroxide.



DDT

[2]

$\text{C}-\text{Cl}_y$ in DDT does not undergo nucleophilic substitution as the lone pair of electrons of Cl delocalises into benzene ring, resulting in partial double bond character in the $\text{C}-\text{Cl}$ bond, hence the bond is not broken easily.

[Total: 16]

[TURN OVER]

- 4 Haemoglobin is a critical protein found in red blood cells that carries oxygen from the lungs to the rest of the body.

Deoxyhaemoglobin and oxyhaemoglobin both contain iron in the +2 oxidation state. Each Fe^{2+} is coordinated to five nitrogen-containing ligands and one oxygen-containing ligand, forming an octahedral arrangement.

In an octahedral complex such as haemoglobin, the 3d subshell of Fe^{2+} is split into two energy levels.

(a) Using the axes in Fig. 4.1, draw **fully-labelled** diagrams of the following.

- One of the d orbitals at the lower energy level in an octahedral complex.
- One of the d orbitals at the higher energy level in an octahedral complex.

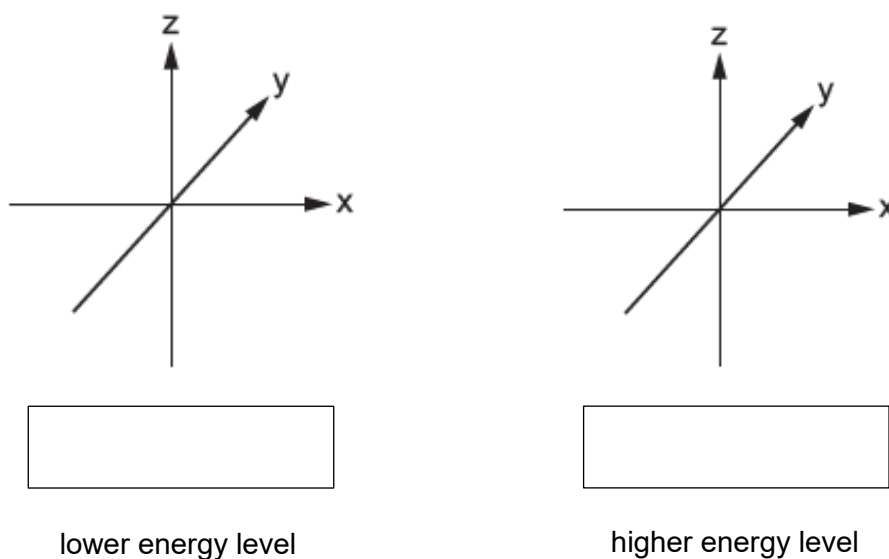
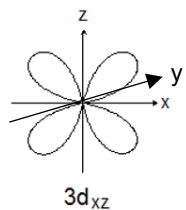


Fig. 4.1

[2]

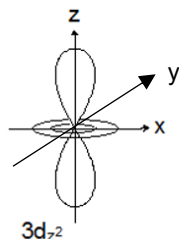
Lower energy level (in between axes)



Comment: aligning with the axis provided, $3d_{xz}$ is the easiest to draw.

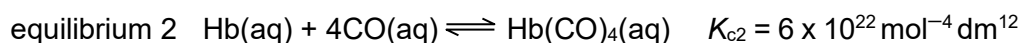
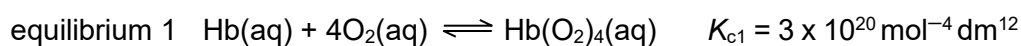
Higher energy level (on the axes)

[TURN OVER



Comment: aligning with the axis provided, $3d_{z^2}$ is the easiest to draw.

- (b) Haemoglobin can react with oxygen and carbon monoxide respectively as shown in the following two equilibria.



- (i) Explain why carbon monoxide is toxic. [1]

Carbon monoxide bonds more strongly via a dative covalent bond, to the iron in haemoglobin. CO is a stronger ligand than O_2 and its presence destroys the O_2 carrying capacity of haemoglobin. Thus, CO is toxic.

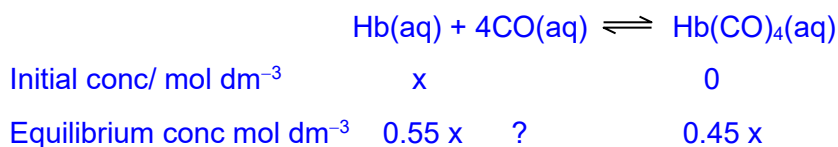
Carbon monoxide bonds strongly via a dative covalent bond due to higher K_c , destroys the O_2 carrying capacity of haemoglobin.

- (ii) Carbon monoxide binds to haemoglobin, Hb, to form carboxyhaemoglobin, Hb(CO)_4 .

If the percentage of haemoglobin bound to carbon monoxide reaches 45%, the result is fatal to humans.

Use the value of K_{c2} to calculate the concentration of carbon monoxide necessary for 45% of the Hb to be converted to Hb(CO)_4 . [2]

Let $x \text{ mol dm}^{-3}$ be the initial concentration of Hb(aq)



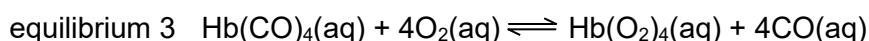
[TURN OVER]

$$K_c = 6 \times 10^{22}$$

$$[\text{CO}]^4 = \frac{0.45 \times}{(0.55 \times) (6 \times 10^{22})}$$

$$[\text{CO}] = 1.92 \times 10^{-6} \text{ mol dm}^{-3}$$

- (iii) Equilibrium 1 and 2 can be expressed as a single equilibrium 3.



Using K_{c1} and K_{c2} , calculate the value of K_c for equilibrium 3. [1]

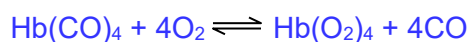
$$K_c = \frac{[\text{Hb}(\text{O}_2)_4][\text{CO}]^4}{[\text{Hb}(\text{CO})_4][\text{O}_2]^4} = \frac{[\text{Hb}(\text{O}_2)_4]}{[\text{O}_2]^4} \times \frac{[\text{CO}]^4}{[\text{Hb}(\text{CO})_4]}$$

$$= K_{c1}[\text{Hb}] / K_{c2}[\text{Hb}] = K_{c1}/K_{c2} = 1/200 = 5 \times 10^{-3}$$

- (iv) Use the K_c value calculated in b(iii) to suggest the position of equilibrium and the sign for ΔG for equilibrium 3. [1]

Position of equilibrium lies to the left and the sign of ΔG is positive

- (v) A patient suffering from carbon monoxide poisoning can be treated by giving pure oxygen to breathe. Suggest a reason why this treatment is effective. [2]



Or with reference to equilibrium 3

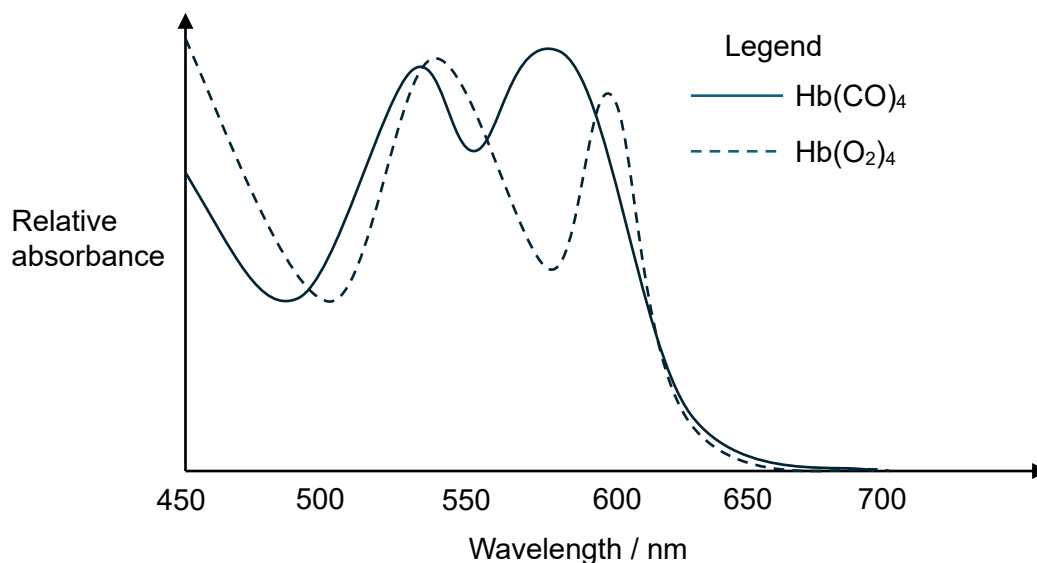
By using pure O_2 , the equilibrium position is shifted right due to the very high concentration of O_2

Or

Mass action effect due to high concentration of O_2

The formation of $\text{Hb}(\text{O}_2)_4$ means that haemoglobin resumes its role as a transporter of oxygen and hence the patient can be revived.

- (c) Carboxyhaemoglobin, $\text{Hb}(\text{CO})_4$, and oxyhaemoglobin, $\text{Hb}(\text{O}_2)_4$, were analysed and the absorption spectrum was observed.



Species	Colour Observed
$\text{Hb}(\text{CO})_4$	Cherry-red
$\text{Hb}(\text{O}_2)_4$	Orange-red

Colour	Wavelength (nm)	Colour	Wavelength (nm)
Violet	380 – 400	Yellow	560 – 580
Blue	400 – 490	Orange	580 – 620
Green	490 – 560	Red	620 – 800

- (i) With reference to the absorption spectrum, explain why both $\text{Hb}(\text{CO})_4$ and $\text{Hb}(\text{O}_2)_4$ are generally red in colour.

[1]

The 650 – 800 nm region is not absorbed, thus red colour is reflected.

OR

Both forms of Hb absorb in the 450 – 620 nm region / green absorbed, hence the complementary colour, red, is reflected.

[TURN OVER]

- (ii) Suggest why $\text{Hb}(\text{CO})_4$ and $\text{Hb}(\text{O}_2)_4$ have different shades of red. [2]

For $\text{Hb}(\text{CO})_4$ and $\text{Hb}(\text{O}_2)_4$, there is a difference in the type of ligand present (O_2 vs CO). This difference resulted in a difference of the extent of the splitting of the d orbitals / in a different energy gap.

[Total: 12]

- 5 Cycling is a demanding endurance sport that pushes athletes to optimise every aspect of their performance. Chemists play a critical role in this field by enhancing bicycle materials, improving energy metabolism in cyclists and in ensuring safety.

- (a) Cyclists often look for ways to reduce the weight of their bicycles, which typically weigh around 7.4 kg. One proposed idea is to inflate bicycle tyres with helium instead of air to reduce weight.

- (i) State two basic assumptions of kinetic theory as applied to an ideal gas. [2]

There are negligible forces of attraction between the gas particles.

The gas particles occupy a negligible volume compared to the total volume it occupies/volume of the container.

- (ii) Using the data in Table 5.1, calculate the respective mass of helium and mass of air required under the same given conditions.

Suggest, with a reason, whether the use of helium provides a significant advantage in terms of mass.

Table 5.1

	Value
Molar mass of helium (He)	4.0 g mol ⁻¹
Molar mass of air (approximate)	29.0 g mol ⁻¹
Volume of gas in a standard bicycle tyre	2.0 dm ³
Pressure in tyre	8 bar
Temperature	298 K

[3]

[TURN OVER]

$$n = PV / RT = (8.0 \times 100000 \times 2.0 \times 10^{-3}) / (8.31 \times 298) = 0.646 \text{ mol}$$

$$m = 0.646 \times 4.00 = 2.58 \text{ g}$$

$$m = 0.646 \times 29.0 = 18.73 \text{ g}$$

Mass saving = $18.73 - 2.58 = 16.15 \text{ g}$ if He is used instead of air.
Compared to the mass of the bike, this is only 0.218 %, hence it is not significant.

- (iii) Rubber tyres are made of vulcanised rubber, a cross-linked polymer. Although they appear solid, they contain tiny free volumes between polymer chains at the nanometer scale, typically around 0.3 – 0.5 nm.

With reference to the *Data Booklet*, suggest why helium should not be used to inflate the tyres.

[1]

Atomic size of He = 0.140 nm

The atomic size of He is smaller than the gaps/holes in the rubber structure of the tyre (0.3 – 0.5 nm). The He can escape easily through the gaps/ resulting in fast leakage.

- (b) A bicycle frame must balance tensile strength, weight, durability and cost. Choosing the right material is key to optimising cycling performance.

Tensile strength is the maximum stress that a material can withstand before it shows significant deformation of its body shape.

Table 5.2

Material	Density (g/cm ³)	Tensile Strength (MPa)	Relative Cost	Corrosion Resistance
Aluminium	2.70	310	Moderate	Moderate
Titanium	4.50	900	High	High
Steel	7.85	500	Low	Low
Graphite Fibre	1.60	600	Very High	High

- (i) Explain, in terms of structure and bonding, why graphite fibre has relatively high tensile strength. [1]

Giant covalent structure with extensive /strong covalent bonds between the carbon atoms.

- (ii) Considering the data provided in Table 5.2, recommend the most suitable material for a high-performance racing bicycle frame. Justify your choice in terms of the factors in Table 5.2. [2]

Rank each material in terms of each factor

Material	Density rank	Tensile Strength rank	Relative cost rank	Corrosion Resistance rank	Total (the lower the better)
Aluminium	2	4	2	2	10
Titanium	3	1	3	1	8
Steel	4	3	1	3	11
Graphite Fibre	1	2	4	1	8

Although titanium and graphite fibre are ranked equally, graphite fibre still wins as it offers much better performance in terms of the density, where the mass of the bicycle is very important, especially when going uphill.

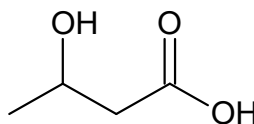
Note: a cheap graphite fibre bike from Decathlon already costs \$990! The most expensive graphite fibre bikes, used by top cyclists, cost more than \$20,000.

- (c) Endurance athletes, such as cyclists, are constantly seeking ways to boost stamina and fight fatigue. One option is to consume BHB energy supplement.

Beta-hydroxybutyrate (BHB), is a lab-made compound that serves as an efficient fuel source for both the brain and body when glucose levels are low.

In cells, BHB enters the mitochondria to produce ATP, which is the body's main source of energy.

Compared to glucose, it generates less waste, helps conserve NAD^+ (a molecule essential for energy metabolism) and avoids blood sugar spikes. However, BHB is also expensive, has a bitter taste, may cause nausea and is absorbed more slowly than glucose. This makes it less ideal for short, intense bursts of energy.

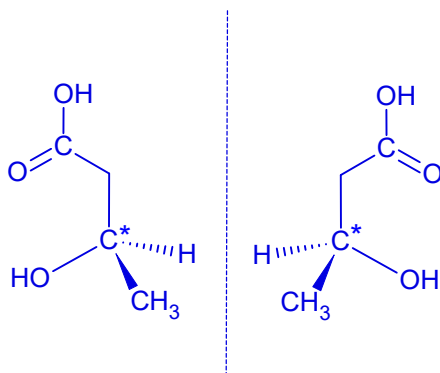


beta-hydroxybutyrate (BHB)

- (i) State the systematic name for BHB. [1]
 3-hydroxybutanoic acid
- (ii) BHB has stereoisomers. State the type of stereoisomerism present in BHB and draw the stereoisomers. [2]

[TURN OVER

Type of stereoisomerism: Enantiomerism / optical isomerism



- (iii) Use the data in Table 5.3, calculate the energy released in kJ g^{-1} for both BHB and glucose when they undergo combustion.

Table 5.3

	Molar mass / g mol^{-1}	Standard enthalpy change of combustion / kJ mol^{-1}
BHB	118.13	-2430
Glucose	180.16	-2805

[1]

Energy per gram for BHB = $2430/118.13 = 20.57 \text{ kJ g}^{-1}$

Energy per gram for glucose = $2805/180.16 = 15.57 \text{ kJ g}^{-1}$

- (iv) Based on your calculations in (c)(iii), suggest whether using BHB as an energy supplement would benefit endurance cyclists. Give a reason for your answer.

[1]

BHB provides more energy per gram ($20.57 > 15.57$)

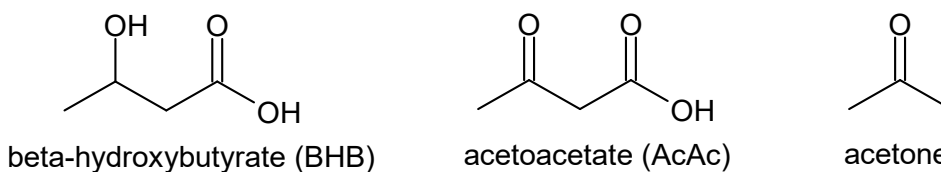
Potential advantages: faster energy release, sustained energy in endurance, produces more ATP, higher energy efficiency, alternative when glucose levels fall as it does not spike blood sugar levels for steady performance.

[TURN OVER

- (v) Suggest a disadvantage of using BHB as an energy supplement. [1]

It is expensive/ taste issues/ bitter taste / causes nausea/ slower digestion / absorbed more slowly than glucose.

- (d) BHB, acetoacetate (AcAc) and acetone are fat-derived compounds made mainly in the liver. They form about 80% of the ketones in the blood and provide energy especially to the brain during fasting, intense exercise or low-carbohydrate diets.



Describe a simple chemical test, with appropriate observations, that can be carried out to distinguish between each of the following pairs of compounds.

- AcAc and acetone
- AcAc and BHB

[4]

- Acetone and AcAc

Add Na_2CO_3 (aq) to both compounds in separate test tubes

Acetone: No effervescence observed.

AcAc: Effervescence is observed in 1 test tube. Gas evolved forms white ppt in $\text{Ca}(\text{OH})_2(\text{aq})$.

- AcAc and BHB

Add 2,4-DNPH to both compounds in separate test tubes

AcAc: Orange ppt formed.

BHB: No orange ppt formed.

OR

Add $\text{KMnO}_4(\text{aq})$, H_2SO_4 (aq), heat to both compounds in separate test tubes.

AcAc: Purple solution remained.

BHB: Purple solution decolourised.

OR

Add $\text{K}_2\text{Cr}_2\text{O}_7(\text{aq})$, H_2SO_4 (aq), heat to both compounds in separate test tubes.

[TURN OVER

AcAc: Orange solution remained.

BHB: Orange solution turned green.

[Total: 19]

END OF PAPER

[TURN OVER